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OBSERVATIONAL STUDY ON MICROSEISMS (PART 2)

BY

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DISASTER PREVENTION RESEARCH INSTITUTE
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(Communicated by Prof. K. Sassa)

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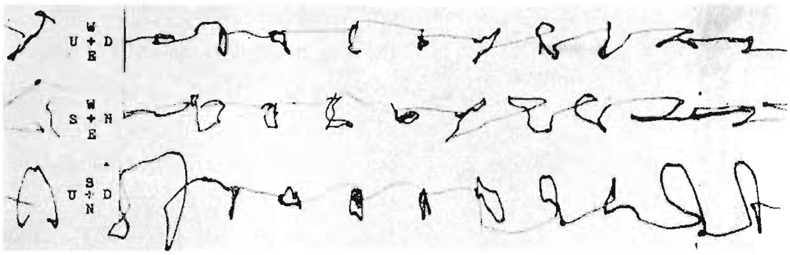
1. Introduction

In the previous paper (Okano 1961) it was shown that microseismic waves are generated by the swells propagated from a disturbance source to the coasts near an observation point. Especially their arrival directions deduced from the orbital motions of ground which were recorded by the vector seismographs, made this inference reserve the writer's entire confidence. The further investigation was made by carrying out the observations at the Aso and the Yura stations. The former station is located at the nearly central part of Kyushu where is surrounded by seas on all sides, and the latter is located at the coast of Wakayama Pref. in the southward direction at the distance of about 100 km from the Abuyama Seismological Observatory. Both stations appear suitable to investigate furthermore the precise location of generation of microseisms. The frequency of arrival directions of microseismic waves obtained at the Aso station is very partially distributed and these partially distributed directions seem to be closely associated with the slope of continental shelves. The frequency distributions obtained at the Abuyama and the Yura stations also support this close relationship. Furthermore the writer intended to investigate whether microseismic waves are generated at the regions close by coast lines or at some distance from coasts. The amplitude of waves coming from different directions supplied some information regarding that problem. But the sufficient elucidation of this subject must be expected by further investigations.

When the typhoon no. 14 in 1960 passed through on the south ocean off Japan, there were appreciable differences of the periods among the microseismic waves coming from different directions. This result is explainable, if the periods of swells increase with an increase of distance of propagation.

2. Arrival directions of microseismic waves at Kyushu

With the same method used at the Abuyama Seismological Observatory, the arrival directions of microseismic waves were deduced by observing the orbital motions of ground at Kyushu. The station where the observation was carried out is the Aso Volcanological Laboratory, located nearly in the central part of Kyushu. The instruments used are the vector seismographs adjusted to the following constants ; $T_1=4.0$ sec., $T_2=6.0$ sec., $h_1, h_2=$ near critical and $V_{max.}=$ about 2800. Some of the orbital motions recorded are shown in Fig. 1. It is found that they are appreciably



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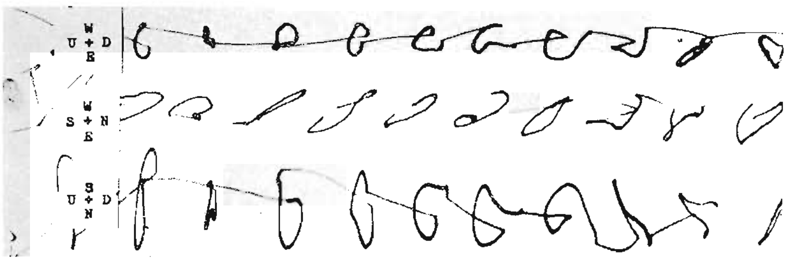

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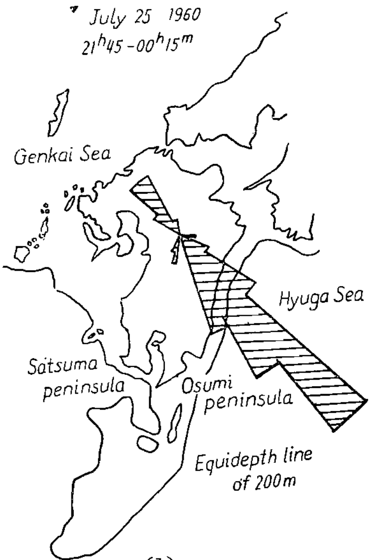
Fig. 1 Seismograms recorded at Aso station.

disturbed and complicated in comparison with those recorded at the Abuyama station, because of superposing by various types of volcanic microtremors (Sassa 1935). Notwithstanding the fact the waves of typical Rayleigh type, disregarding the slight deformation, are found so frequently that the frequency distribution of arrival directions can be obtained without difficulty. Fig. 2 shows the three distributions obtained from the microseismic storms generated by the typhoon no. 6, no. 8 and no. 18 in 1960, and Fig. 3 shows the respective weather charts at the times when those distributions were obtained. When those distributions were obtained, the typhoons regarded as the disturbance sources were on the south-westerly ocean far off Kyushu. Most of the arrival directions do not point toward the centers of the typhoons, though there are a few pointed toward the south-westerly coast where considerable parts of swells arised in the typhoon areas are supposed to be sent, judging from the location of the typhoons. A great part of the frequencies is concentrated in the south-easterly direction (the Hyuga Sea), and a small part of them indi-



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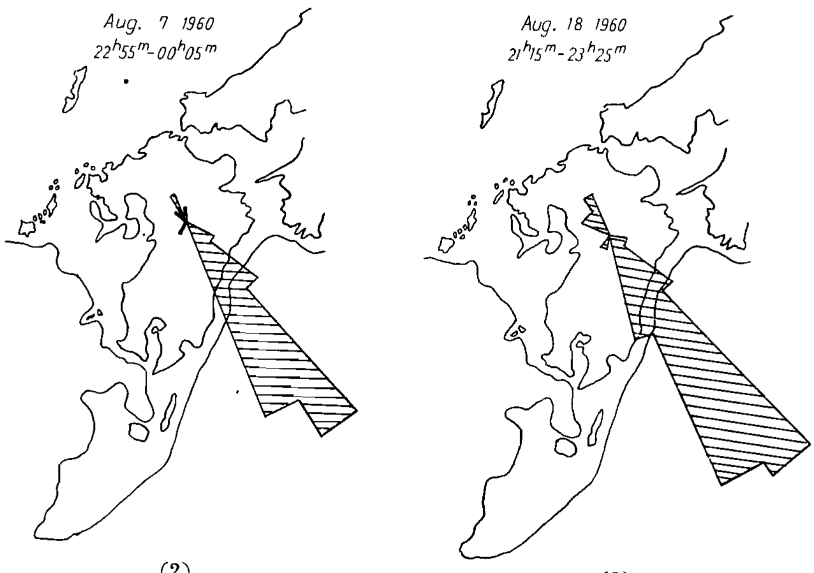

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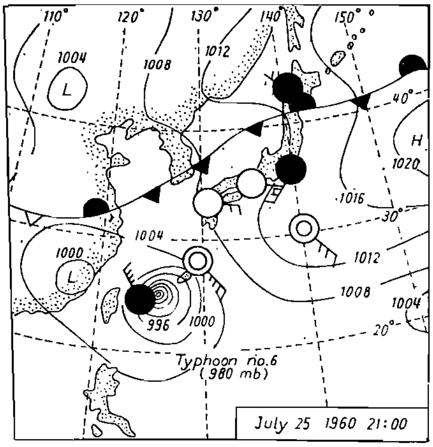
Fig. 2 Frequency distributions of arrival directions of microseismic waves observed at Aso station.



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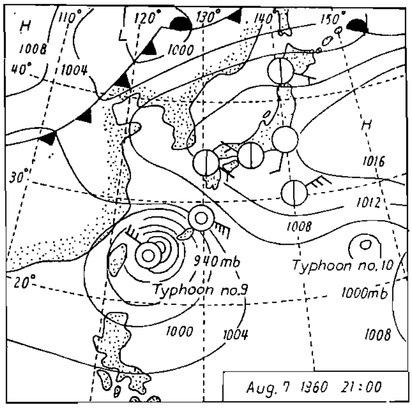

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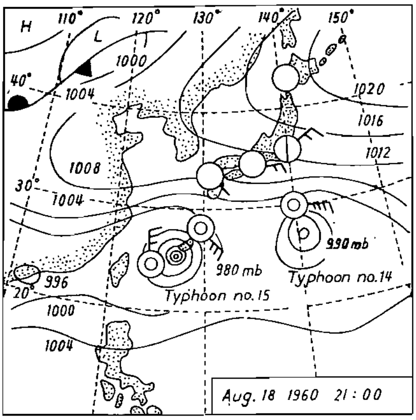

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Fig. 3 Weather charts at the respective times when Fig. 2 was obtained.

cates the north-westerly direction (the Genkai Sea), though the microseismic storm on July 25 in 1960 when the cold front passed over the Genkai Sea distributes considerable frequencies in that direction. And a little rests of the frequencies are distributed only in the direction of the Satsuma Peninsula. Previously the writer deduced from the arrival directions of microseismic waves at the Abuyama station that there are some districts where microseismic waves are frequently generated and some other districts not frequently. These observations at Kyushu supported more firmly this inference. Vertical components, as shown in Fig. 1, are small in amplitude as compared with horizontal, whereas the seismographs at the Abuyama station recorded the microseismic waves with similar amplitudes in two components. This may be due to the property of the ground on which the Aso station is founded.

3. Arrival directions of microseismic waves at the Wakayama Pref.

To obtain further information on the generating district of microseismic waves, the arrival directions were observed at the Yura observing station of the Wakayama Pref. by the vector seismographs used for the same purpose at the Abuyama station.

When the seasonal wind stirred up the Japan Sea on Dec. 6 in 1960, the observation was carried out for about five hours. The seismographs recorded frequently the orbits of the considerably typical Rayleigh motion, having the amplitudes in vertical component similar to those in horizontal, as recorded at the Abuyama station. An example of those orbital motions is shown in Fig. 4. Fig. 5 shows the frequency distribution

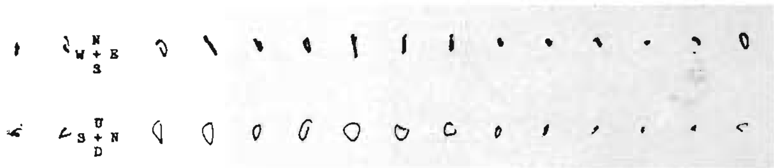


Fig. 4 Seismogram recorded at Yura station.

of arrival directions read from those orbits. Notwithstanding that the Yura station is far more distant from the coast of the Japan Sea than that of the Pacific, almost all arrival directions point toward the Japan Sea. And the pattern of the distribution is very similar to that of the Abuyama station, that is, the microseismic waves do not come from the easterly and westerly directions in which there are no coasts of the Japan Sea close to the station. The direction indicating the maximum frequency does not coincide with the northward direction in which the station is nearest to the

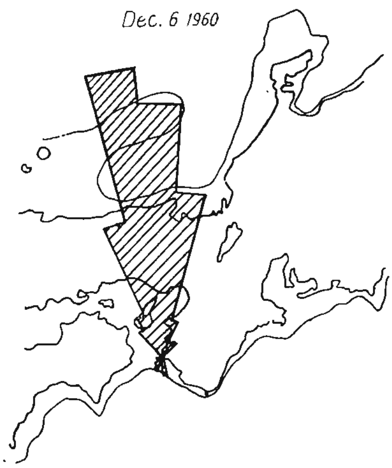


Fig. 5 Frequency distribution of arrival directions of microseismic waves observed at Yura station.

Japan Sea, but deviates somewhat westwards. We may recognize the difference of about 10 degrees between the deviation of arrival directions at the Abuyama station and that at the Yura station. The existence of the difference appears to support the writer's opinion on the origin of microseisms.

4. The microseismic storm observed at the Abuyama station on Aug. 20 1960

The strong microseismic storm was raised when the typhoon no. 14 passed over the southerly ocean of Japan. The vector seismorgraphs recorded the orbital motions of ground in horizontal and only one vertical (UD-NS) planes, and simultaneously an ordinary seismograph with the same constants as the vector seismographs recorded the ground vibration in NS component. The arrival directions were read from the former and the wave period from the latter, because the vector seismographs are hard to give the wave period so exactly as read from an ordinary seismograph. And if we intend to select only the waves of the typical Rayleigh form, the orbital motions in the horizontal and only one vertical (UD-NS) planes may supply the sufficient information for the arrival direction. Of course, if the microseismic waves come from

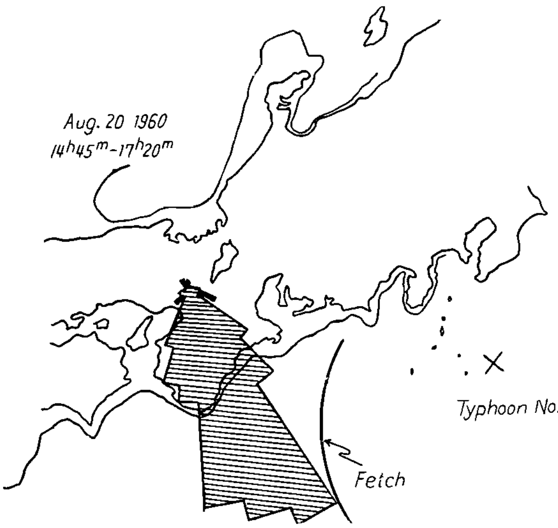


Fig. 6 Frequency distribution of arrival directions of microseismic waves observed at Abuyama station on Aug. 20 1960 and location of the typhoon.

the easterly or westerly direction, the orbits in another vertical (UD-EW) plane are necessary to detect such waves. But the writer could save the necessity of those orbits, because he did scarcely find the east-westerly linear orbits with comparable amplitudes in the horizontal plane. The frequency distribution of arrival directions is shown in Fig. 6. The arrival directions do not point toward the center of the typhoon, and the direction of maximum frequency deviates considerably eastwards from the south, differing from that obtained previously. This may be ascribed to that the typhoons were westwards from the Kii Peninsula in the previous case and eastwards in this case and hence the swells propagated from the respective typhoon areas were interruped by the Peninsula.

5. Consideration on the district where microseismic waves are generated

The frequency distribution of arrival directions of microseismic wave having the typical Rayleigh motions is shown in Fig. 7, including the new data obtained by the observation at the Abuyama station. Examining these distributions obtained at the Abuyama, the Aso and the Yura stations, it comes into notice that the microseismic waves originate definitely in the particularly limited regions while the center of typhoon moves. The writer recognized that the frequency of generation is closely connected with the slope of the continental shelf. The equidepth lines of 200 meters drawn in those figures suggest that fact, and it is indicated furthermore clearly by Fig. 8. In this case the frequency of generation is supposed to be also associated with an angle of the arrival direction formed with the continental margin, besides a slope of the continental shelf, because the origin of

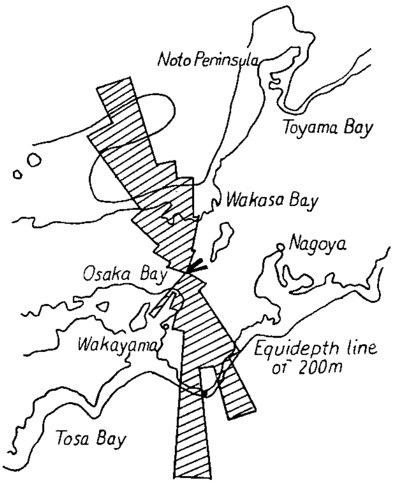
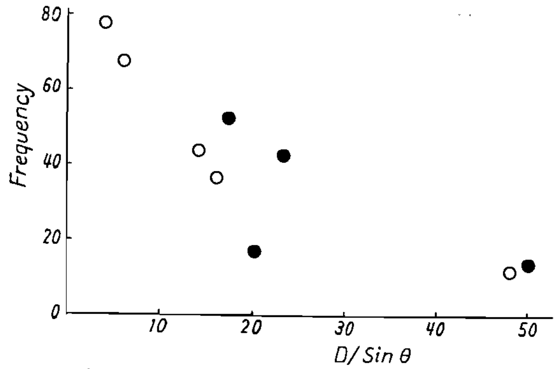
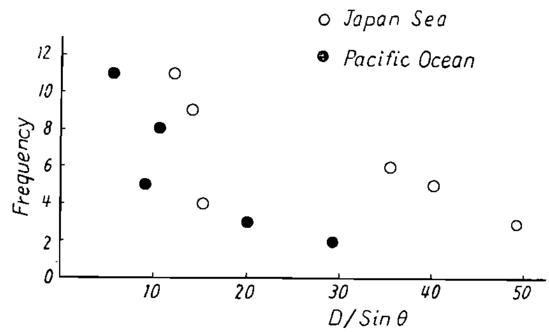


Fig. 7 Frequency distribution of arrival directions of only microseismic waves having the typical Rayleigh form. (at Abuyama station)



(1) ○ - Yura station, ● - Aso Laboratory



(2) Abuyama Observatory

Fig. 8 Relationship between the frequency of microseismic waves and the ratio of D to Sin θ.
D : Distance from coasts to continental margins
θ . Angle of arrival directions formed with continental margins

microseisms is taken as the line source which is parallel with the continental margin. Therefore $D/\sin\theta$ was adopted as the abscissa, in which D is the distance from the coast to the continenental margin and θ is the above mentioned angle. It may be readily understood from the above mentioned inference that there are minimum frequencies in the southerly direction in their distributions at the Aso station and also in the direction of the Wakayama district and the Noto Peninsula in the distributions at the Abuyama station.

Let us consider why we observe frequently the microseismic waves coming from the regions possessing the continental shelves of steep slope. As the wave length of sea waves is comparable to the depth of the continental shelf, the wave energy is dissipated as a result of friction by the oscillating motion of waves at the sea bottom, and in consequence the wave height reduces as the waves propagate shoreward. Accordingly as a decrease of the slope of shelf, the sea waves reduce in height in the vicinity of the coast, because of dissipating of the energy due to an increase of the distance of propagation, and then it results in the reduction of amplitudes of microseismic waves. The arrival direction may be thus not frequently observed by us in the direction of the gently sloping continental

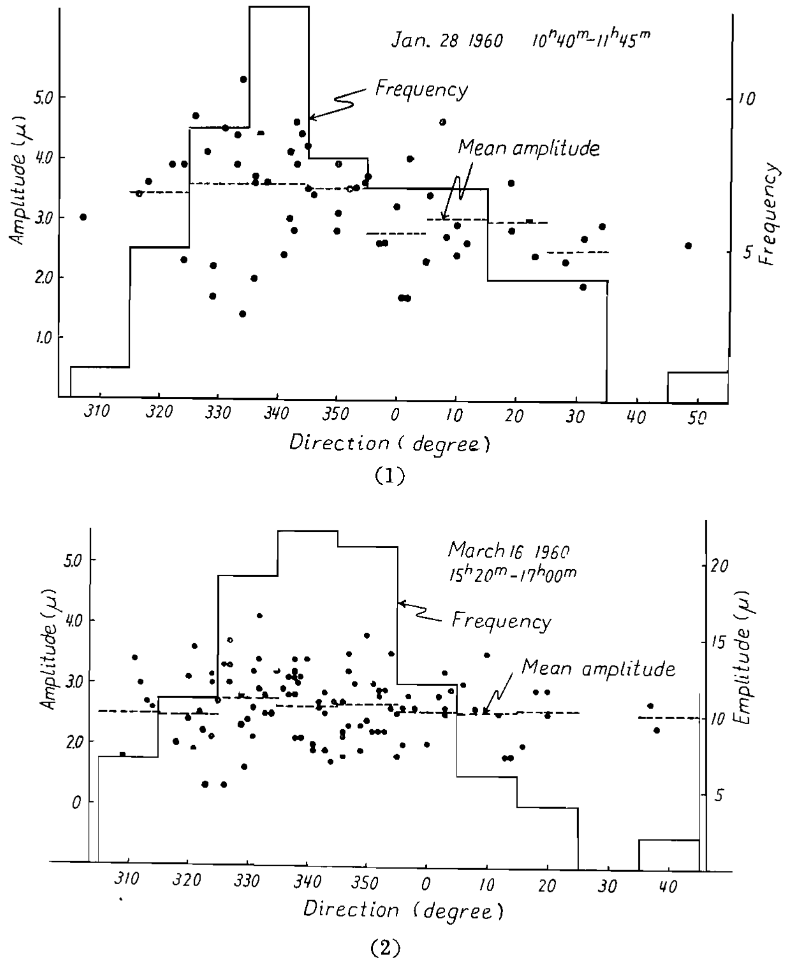


Fig. 9 The amplitude of microseismic waves versus the arrival direction.

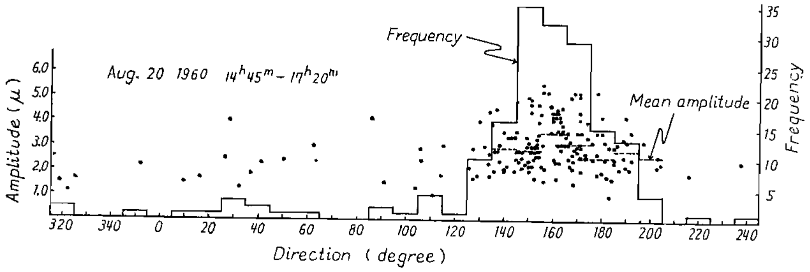


Fig. 10 The amplitude of microseismic waves versus the arrival direction.

shelf. If it is so, the amplitude of microseismic waves should be in proportion to the frequency of arrival directions. The relation between the amplitude and the arrival direction is shown in Fig. 9 for the microseismic waves coming from the Japan Sea and in Fig. 10 for those coming from the Pacific. The broken lines in those figures indicate the mean amplitudes. We may observe the upper limiting points plotted to be somewhat proportional to the frequency, but the fluctuation of the amplitude fad into insignificance in comparison with that of the frequency, especially for the mean amplitude. The writer could not thus recognize the close connection between the amplitude of microseismic waves and their frequency of generation. From this fact it is hardly likely that microseismic waves with the energy enough to be propagated to the Abuyama station may be generated at the regions close to the coastlines. The writer does not readily accept the consideration that the microseismic waves should be generated by the standing sea waves due to the interference of incident and reflected waves produced by a steep coast, because he wonders if the standing sea waves can so strongly generate elastic waves in the crust that the ground displacement is able to attain to a few microns after propagating the path of more than 100 km.

According to the experimental study of Cooper and Longuet-Higgins (1951), the first order pressure variations by progressive water waves give considerable energy in the bed of tank, if the water depth is small as compared with half the wave-length. Therefore, the progressive sea waves must more strongly generate microseismic waves than the standing sea waves in sea beds close to coastlines, because the progressive waves, in general, give more energy in phase in sea beds than the standing sea waves.

The writer prefers the district at a distance from the coast, that is, rather near the continental margin, to the district close to the coastline as the origin of generation of microseisms.

In conclusion steeper inclination of the sea bed must be accompanied by the condition to generate more frequently micorseismic waves, and at present we can but guess that the standing sea waves are frequently produced under such a condition.

6. Investigation of the wave period of microseisms coming from different arrival directions

It is interesting and very significant to the investigation of microseisms to observe whether the microseismic waves with different periods come from different arrival directions. The observation to this purpose was carried out at the Abuyama station for the microseismic waves coming from the Japan Sea and the Pacific.

When the progression of microseismic waves was previously investigated (Okano 1960), the ordinary seismograms in NS component were obtained together with the vector seismograms. Therefore the wave period could

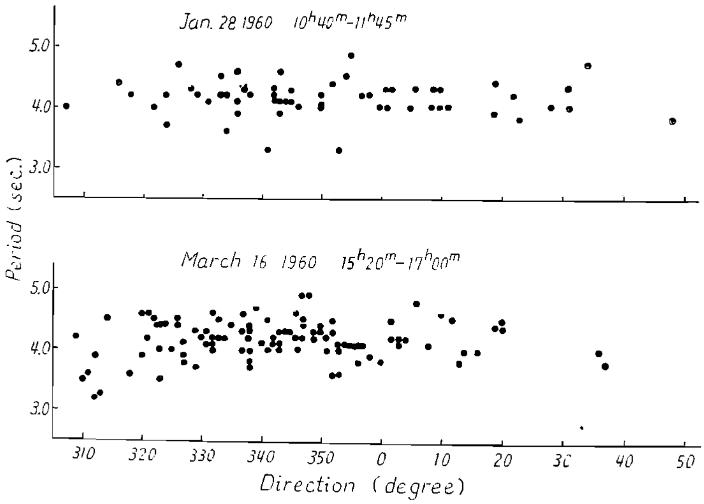


Fig. 11. Relation of the period to the arrival direction of microseismic waves caused by seasonal winds in winter season.

be exactly read from the former and the arrival direction from the latter, and those relations are illustrated in Fig. 11. Although the period are considerably scattered centering around about 4.2 sec., on the whole there is little if any difference among those of waves coming from different directions. The writer supposed that those facts can be interpreted as follows. Since the seasonal wind stires widely up the Japan Sea in winter season, the disturbance source also covers a wide range of the Sea, and hence it is not so distant from the continental margin where the writer considers to be the origin of generation. Accordingly the wave period of microseisms is not so large because of the short distance of propagation of sea waves and it is not so different among the waves generated at the different districts.

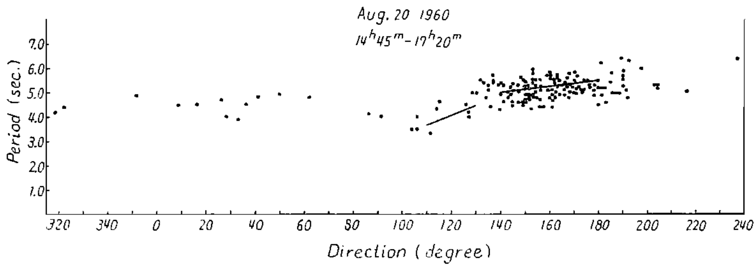


Fig. 12 Relation of the period to the arrival direction of microseismic waves caused by typhoon No. 14.

Fig. 12 shows the relation of the period to the arrival direction of microseismic waves when the typhoon no. 14 was situated as shown in Fig. 6. The difference of the periods among arrival directions is considerably noticed, excepting the waves propagated from the Japan Sea. Then we assume that the swells leave the end of the fetch shown in Fig. 6, propagate on the open sea and generate the microseismic waves in the vicinity of the continental margin. According to Sverdrup and Munk (1947), the relation of the wave period of swells at the end of the decay distance to that at the end of the fetch was indicated as follows.

$$\frac{T_D}{T_F}=\sqrt{1+16\pi^2\,\mathrm{Ar}\,\left(\frac{D}{gT_F{}^2}\right)}$$

$$A\ :\ 2\gamma^2\,\rho'/\rho=6.35\times10^{-6}$$

γ^2 : Resistance coefficient applicable to wind (2.6×10^{-3} for wind velocities 5m/sec)

ρ' : Density of air (1.25×10^{-3} g/cm^3)

ρ : Density of water (1.025 g/cm^3)

r : Coefficient of energy partition (0.580)

D : Distance of decay

Based on the probable assumption that T_F is 6.0 sec., T_D was calculated for each arrival direction, and the relation are indicated by the solid lines in Fig. 12. In this case the writer applied the Longuet-Higgins's theory to the relation between the period of microseismic waves and that of swells, according to which the former is half of the latter. Comparatively good coincidence is recognized between the observation and the calculation. This is one of the evidences to show that the microseismic waves should be generated in the neighbourhood of the continental margin by the swells propagated from the disturbance source. The waves of the short period coming from the direction of 100-110 degrees may be the 3-second microseisms which are very frequently observed at Nagoya. (National Comittee for I.G.Y. 1959 and 1960).

7. Summary

1. The inference that microseismic waves are generated not in the neighbourhood of a low pressure center but at the regions near coasts, became quite obvious from the observations at the Aso and the Yura stations.

2. The microseismic waves are more frequently generated at the district where the continental margin is more shoreward, namely, the slope of the continental shelf is steeper.

3. The writer could not see the appreciable differences in mean amplitude among the waves coming from different directions. This fact suggests that microseismic waves should be generated at the districts not close to coastlines but rather near continental margins, because the swells are supposed to be alike in height everywhere in the vicinity of continental margins.

4. The microseismic waves coming from different arrival directions are alike in mean period when the waves are generated by the seasonal

wind in winter season. When the microseismic waves are generated by the typhoon, we may observe longer periods for the waves propagated from the district having longer distance of propagation of swells.

8. Acknowledgment

Much of this work was suggested by Professor Kenzo Sassa of Kyoto University, to whom the writer owes thanks for his interest and encouragement. The writer wishes to express his thanks to Professor Haruo Miki of Kyoto University for his encouragement. The writer is greatly indebted to Mr. Kosuke Kamo of the Volcanological Laboratory of Kyoto University for the observation at the Aso station.

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